

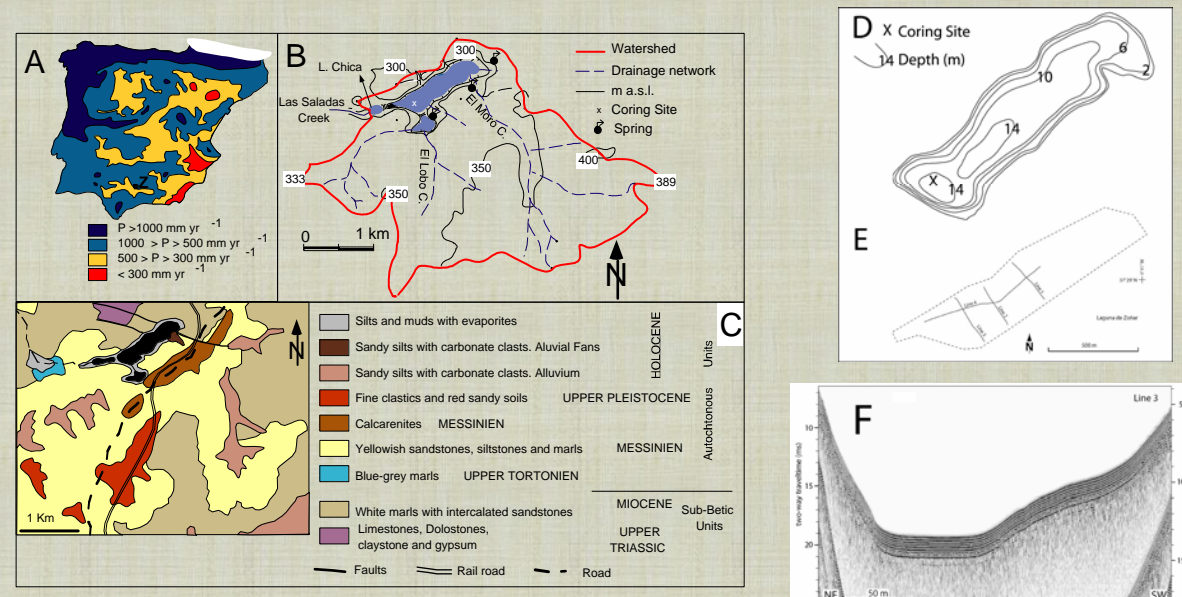
PALEOHIDROLOGY AND HUMAN IMPACT INFERRED FROM SEDIMENTARY FACIES ANALYSES: THE LAGUNA ZOÑAR RECORD (ANDALUCIA, SPAIN)

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THE LAKE AND THE WATERSHED

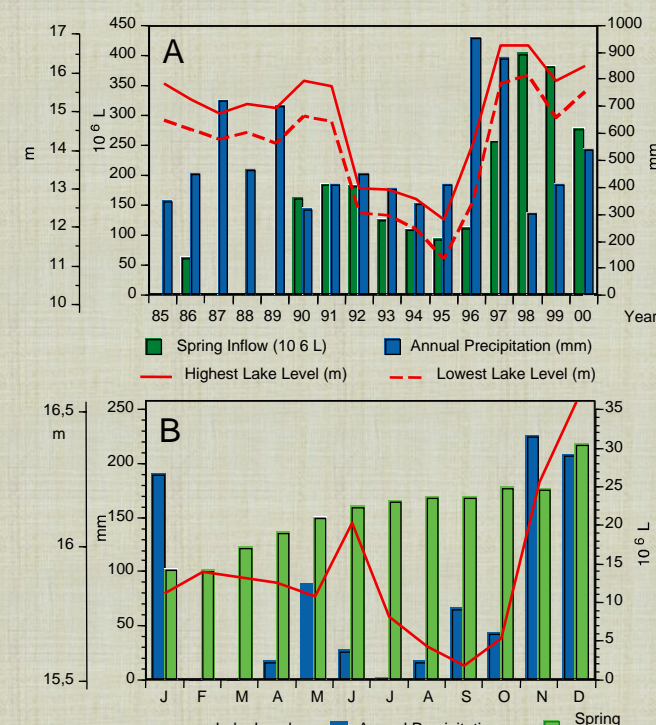


The climate is sub-humid Mediterranean, with an average annual rainfall of about 540 mm (< 300 mm during dry years) and with an annual evapo-transpiration estimated over 1500 mm (A). Laguna Zañar (37° 29' 00" N, 4° 41' 22" W, 300 m a.s.l.) is the deepest (up to 14 m, see bathymetry in D) and largest (37 ha, surface area) of the 10 lakes that belong to the Natural Park of Southern Còrbova (Andalucía, Spain) (B). The lake is monomictic; waters are saline (2,4 gL⁻¹), alkaline and of (Cl⁻)-(SO₄²⁻)-(Na⁺) type. The lake is mainly fed by springs located in the S and E margins, and there is one non-functional surface outlet. The main aquifer is located in the Tortonian limestones (C). A seismic survey (E) showed the steep lake margins and the Arroyo del Lobo delta (F), but there was no sediment penetration.

CHANGES IN THE PAST

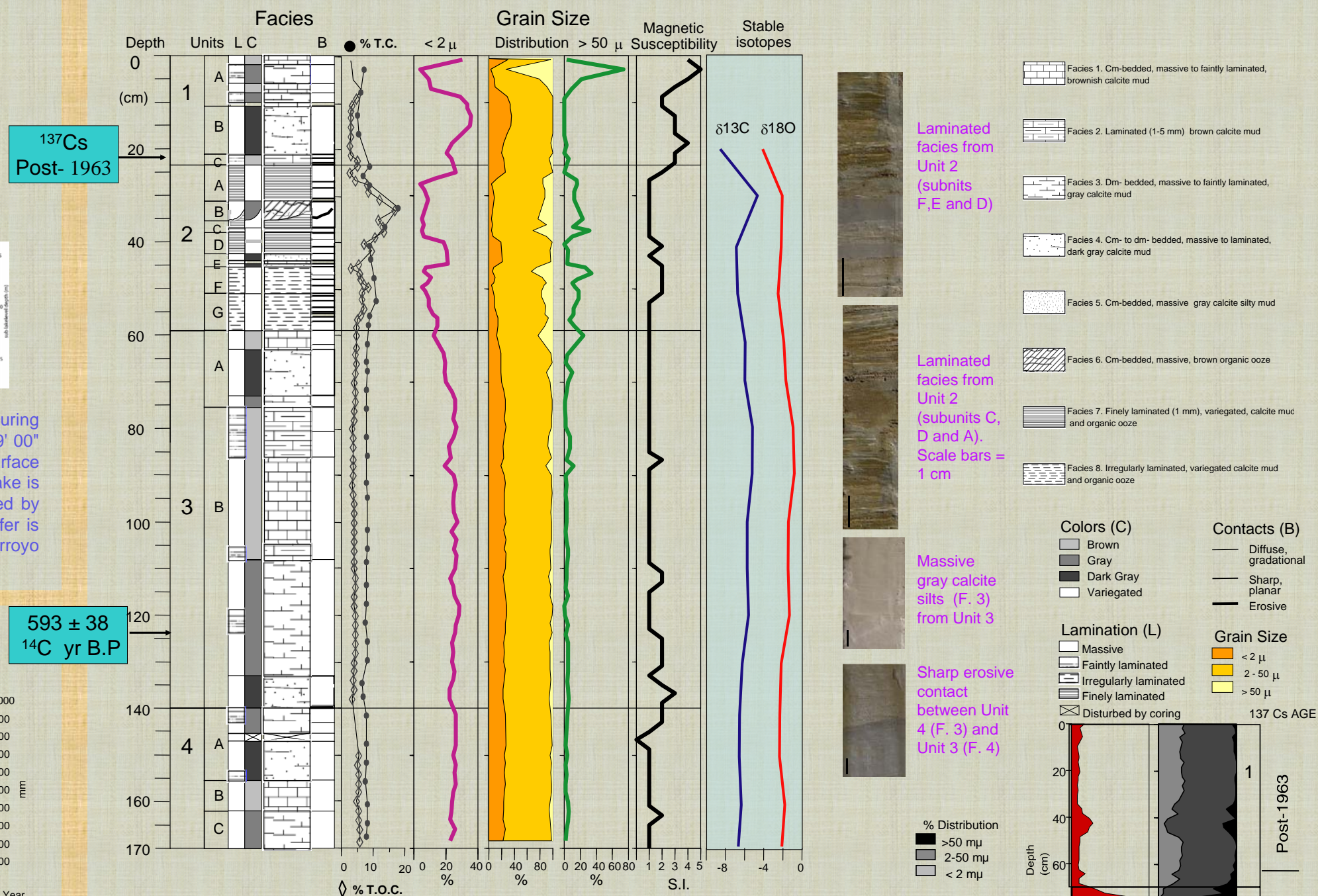


The watershed has been intensively farmed during centuries. Historical records indicate the lake was deeper in the late 19th century. The only surface outlet to the Cabras River was deepened to drain the surrounding areas and also partially the Zañar Lake during the late 19th and early 20th century. In the 1960s, surface and groundwater were diverted for human use, and lake level dropped even more. Since the lake was protected in the early 1980s, lake level recovered and large littoral areas were submerged. The surface outlet was flooded but it was not-reopen, so, today, the lake has not surface outlet.



A. Relationship between annual water input (rainfall and spring flow) and lake level (maximum and minimum) during the period 1985-2000. B. Relationship among water input (rainfall and spring flow) and lake level during 1987.

THE SEDIMENT RECORD OF PAST CHANGES



Eight sedimentary facies have been identified after integrating visual description, smear slide observation and sediment composition analyses. They group in two facies associations: Facies Association A integrates cm- to dm- bedded, massive to slightly laminated calcite muds (F. 1, 2, 3 and 4). Facies Association B integrates finely laminated (F. 7 and 8), organic-rich (F. 6) and cm-thick, massive, calcite mud (F. 5) facies. Facies association A represents deposition during periods of variable, but significant clastic input from the Lobo and Moro creeks. Increased sediment input from the creeks could respond to increased river flow and rainfall and/or changes in the land uses, including the size of the littoral vegetated area. The absence of lamination in the sediments indicates intense bioturbation activity, and likely frequent oxic conditions in the water column till the bottom of the lake. Facies Association B represents deposition in Zañar Lake during a period of a more restricted clastic input from the creek. Preservation of lamination indicates absence of bioturbation, most likely provoked by anoxic bottom water conditions. Diatom blooms and "carbonate whittings" events are registered as thin green and white laminae respectively. Rare flooding episodes deposited thin clay-rich gray laminae (Facies 5). These variegated, organic-rich laminated facies are interpreted as the result of deposition during a period of relatively higher water concentration, when Zañar Lake did not have a surface outlet and the average lake levels were lower.

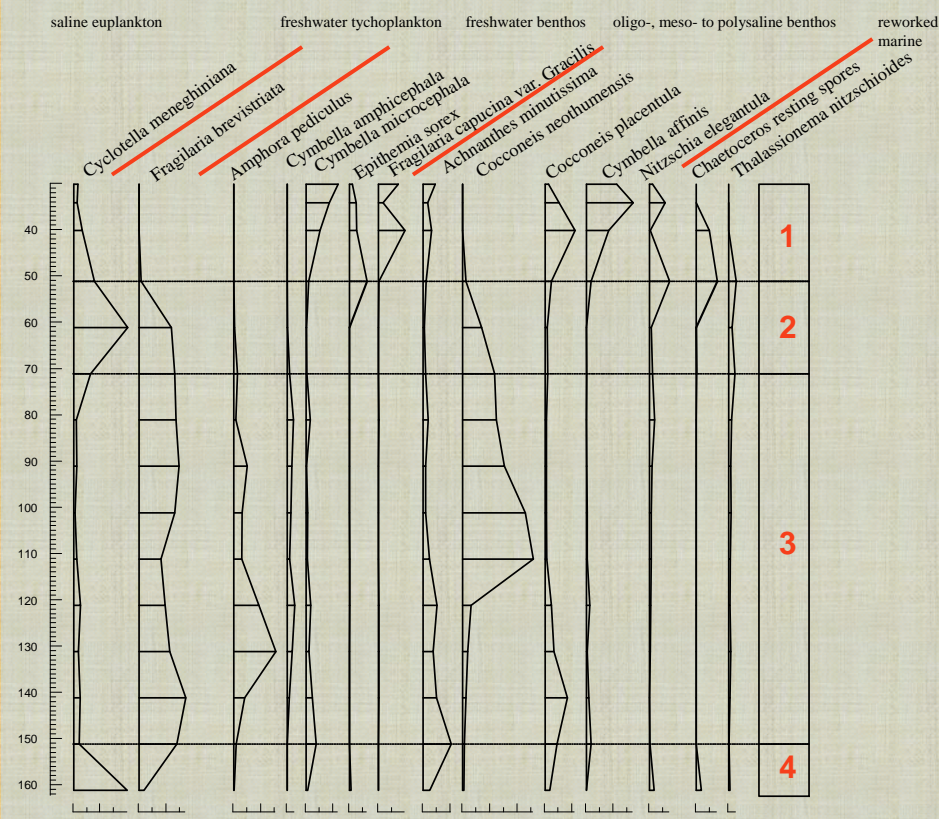
THE LAKE HISTORY

Unit 4 is composed of Facies Association A (F. 1, 3 and 4). The cm-thick facies alternation suggests relatively rapid changes in the lake, particularly in the fluvial input. A distinctive flooding episode marks the onset of Unit 3. Unit 3 is composed of two sequences that represent the gradual transition from a clastic-dominated lake subenvironment with significant fluvial input, to a mixed clastic-authigenic subenvironment. Unit 2 is defined by the occurrence of finely laminated facies, high organic matter content values (10 – 30 %), low magnetic susceptibility values and the smallest fine particle content of the whole core. The high percentages of relatively large particles record the presence of large diatoms. This unit is composed of facies association B that groups facies 5, 6, 7, and 8. The interpreted depositional environment is a brackish to saline lake that facilitated the development of bacterial and algal benthic communities, and with anoxic bottom waters that prevented bioturbation. The low clastic input and the higher salinity suggest generally lower lake levels than during previous units. Seven different subunits have been identified from the relative abundance of the four laminae types, and the characteristics of the lamination. The base of Unit 1 (Subunit C) still shows some faint lamination and relatively high organic matter values (F. 2). Dark gray, massive sediments (F. 4) with high magnetic susceptibility values constitute subunit B. Low diatom content and high clastic input characterize this facies. The most recent sediments (subunit A) are composed of massive and faintly laminated, brown sediments (F. 1 and 3). A large increase in magnetic susceptibility occurs near the top, correlating with the highest values for large sized particles. These large particles do not correspond to diatoms, but to large oxidized organic matter remains, soil particles and littoral plant remains. The different thickness of the Upper Unit 1 in core A1 (25 cm) and core A2 (70 cm) suggests an uneven sedimentation rate over the basin, characteristic of limnic systems dominated by fluvial processes. This fits with the assessment of large fluvial input from the Lobo and Moro Creek during the last decades. The large limnological change from Unit 2 to Unit 1 seems to have started in the 1950s and it could have been accelerated once the lake was declared a protected area in the early 1980s. Human activities seemed to have played a more significant role than climate variability in these changes in lake hydrology and watershed features during the last decades. However, the direct relationship between rainfall and lake level observed in the lake during the last decades suggest that climate variability could have been the main controller of lake level in the past.

The Zañar Lake case study underlines the potential of sedimentary facies analyses as a tool to unravel paleoenvironmental and paleohydrological information from lacustrine cores. They provide "qualitative" reconstructions as useful as the "numeric" reconstructions provided by other proxies. The paleolimnological information obtained through a detailed facies analyses also helps to interpret other proxies with ambiguous interpretations.

Diatoms

Diatom assemblages are dominated by the tychoplanktonic *Fragilaria brevistriata*, and the periphytic *Cocconeis neothumensis* throughout most of the core. Some levels also have large numbers of the planktonic *Cyclotella meneghiniana* and the periphytic *Amphora pediculus* among others. Reworked marine diatom taxa include *Chaetoceros* resting spores, *Actinocyclus senarius*, *Thalassionema nitzschioides*, *Asteromphalus* sp. and *Neodenticula* sp. *Fragilaria brevistriata* dominates or co-dominates with *Cocconeis neothumensis* in the bottom of the core. There is however a sharp decrease in both species as well as in *Cyclotella meneghiniana* at the 60-25 cm interval coinciding with Unit 2. Those taxa are mainly substituted by the periphytic *Fragilaria capucina* var. *gracilis*, *Cymbella affinis*, *Cymbella microcephala*, *Cocconeis placentula*, and *Nitzschia elegantula*. These preliminary data would indicate a change from deeper or more open waters to shallower conditions with important macrophytic development.



Ostracods

The valve content is low, but the ostracod record correlates with sedimentary facies. - Massive Facies: Dominance of *Ilyocypris* sp., (flowing water conditions) - Laminated Facies in Unit 2 and Unit 3 are devoid of ostracods, likely as a result of restricted water circulation and low oxygen content. - *Candona* sp., is only present at 82-84 cm, which could indicate an interval of relatively deeper waters. - Unit 4 is dominated by *Potamocypris* sp., typical of littoral environments.

Pollen

Terrestrial vegetation: Mediterranean landscapes dominated by *Quercus ilex-coccifera* type, Cupressaceae and *Olea*. Large increase in olive tree cultivation during the 20th century (top Unit 2 and Unit 1)

Aquatic vegetation:

Unit 4: highest percentages of *Myriophyllum spicatum* and it is the only one with *Potamogeton* and *Ruppia*. Lake waters were fresher than today, likely due to a higher fluvial input.

Unit 3: Highest taxonomic diversity. Increase in plants from vegetated lake margins (Tamarix, Sparganium).

Unit 2: Freshwater aquatic plants disappear and hygrophite plants typical of littoral vegetation reach the highest percentages.

Unit 1: the decrease in hygrophite pollen content is interpreted as a reflection of the disappearance of vegetated littoral areas when lake level raised; the absence of aquatic plants suggests that high water turbulence or chemical concentration prevented freshwater aquatic plants development during the last decades.